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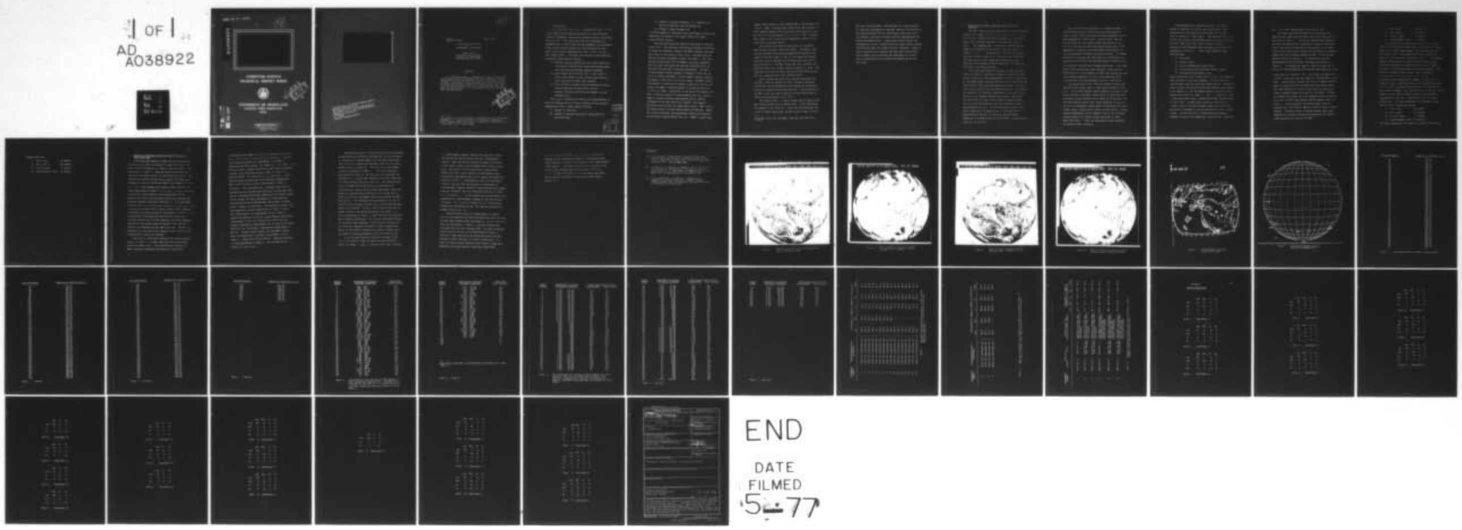

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CLOUD CLASSIFICATION:

EXPERIMENTAL EVALAUTION

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ABSTRACT

In a previous report, a comparative study of statistical cloud classification techniques for discriminating scanning radiometer visible and infrared tropical cloud data was described. The present report explores the effects on classification performance of changes in the satellite, the location and time of observations, the sample window size, and the testing procedure (i.e., testing on a data set different from the design set).

The support of the Directorate of Mathematical and Information Sciences, U. S. Air Force Office of Scientific Research, under Contract F44620-72C-0062, is gratefully acknowledged, as is the help of Mrs. Shelly Rowe.

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1. Introduction

In a previous report [1], a comparative study of statistical cloud classification techniques for discriminating scanning radiometer visible and infrared tropical cloud data was described. The study was primarily concerned with determination of the optimal design parameters for automatic cloud classification systems for discrimination of four basic cloud classes designated as "low", "mix", "cirrus", and "cumulonimbus". The major conclusions of the study may be briefly summarized as follows:

1) Optimal feature combinations for cloud classification should include both visual and infrared spectral features and exclude textural features.
2) Multi-stage decision tree logic is not significantly more effective than single-stage decision tree logic for the four-class problem.
3) Classification accuracy can be improved by designing discriminant functions which assume unequal covariance matrices and unequal a priori probabilities.

This report explores the effects on classification results of changing various factors external to the pattern recognition system. These factors include:

1) change in satellite
2) change in location and time of observation of satellite data

3) change in testing procedure, i.e., testing on a data set different from the design set

4) change in sample window size

A limited number of experiments were performed to assess the importance of changes in the above factors on cloud classification results.

The digitized satellite data for the study in the previous report was obtained from analog-to-digital conversion of scanning radiometer signals from NOAA-1 whereas the data sets used for the study in this report resulted from processing scanning radiometer signals from SMS-1. The infrared and visible data from the NOAA-1 scanning radiometers have the same resolution and spectral characteristics as the data from the SMS-1 scanning radiometers. The SMS-1 visible channel sensors respond to energy in the 0.55- to 0.75- μm range; the NOAA-1 visible channel sensors respond to energy in the 0.52- to 0.72- μm range. The SMS-1 infrared channel is sensitive to energy in the 10.5- to 12.6- μm range; the NOAA-1 infrared channel to energy in the 10.5- to 12.5- μm range. Resolution at the satellite subpoint for SMS-1 infrared channels is approximately 2x4 n.mi. and for NOAA-1 infrared channels approximately 4n.mi. Orbital altitudes of the two satellites, however, and range of possible values of the raw ingest data differ. SMS-1 orbits at geostationary altitude (approximately 36,000 km). NOAA-1 was a polar-orbiting, sun-synchronous satellite located at an altitude of approximately 790 n.mi. NOAA-1 visible data

ranges from 0 (black) to 255 (white); SMS-1 visible data from 0 to 63. NOAA-1 infrared data ranges from 160.0 (white) to 330.0 (black) degrees Kelvin which was re-scaled by a shift of -160 for the experiments in this report. SMS-1 infrared data ranges from 0 (warm end of temperature scale) to 255 (cold end) calibrated counts.

The location and time of observation of the NOAA-1 data set and the SMS-1 data sets differ. The NOAA-1 data set was selected from digitized data which resulted from signals received on May 3, 1971 as the spacecraft passed over the tropical eastern Pacific Ocean west and south of Baja California.* The SMS-1 data sets were selected from digitized data from an SMS-1 orbit of January 9, 1975. The latitude limits for the SMS-1 design set were 35°N to 35°S and the longitude limits were 125°W to 25°W.

Both a design set and a test set were selected from the SMS-1 orbit of January 9, 1975. Maximum likelihood classifiers were designed using the design set and tested on both the design set and the test set. A description of the SMS-1 data sets and an analysis of the classification results are presented in this report.

Two window sizes -- a small window size of 64x32 pixels and a large window size of 64x64 pixels -- were considered for samples in the test set. Since the digitized data consisted of 64x64 registered, paired arrays of SMS-1 visible

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*Latitude limits for the NOAA-1 data set were 26.7°N to 1.1°S.

2x2 n.mi. data and SMS-1 infrared 2x4 n.mi. data spaced at 5° intervals longitudinally and $2\frac{1}{2}$° intervals latitudinally, the maximum window size for which both visible and infrared features could be extracted from the same geographical region was 64x32 pixels. Cloud-truth classification and consequently a priori probabilities of cloud classes changed significantly when the window size was increased. Comparison of classification results for small and large window sizes enables one to evaluate the importance of factors such as compatibility of window size between design and test sets.

2. Description of SMS-1 Data Sets and Cloud Truth Analysis

The SMS-1 data sets which were used to evaluate pattern recognition systems in the previous report were selected from digital VISSR (Visible and Infrared Spin Scan Radiometer) data obtained from SMS-1 on January 9, 1975 at 1630 z. The unmapped SMS-1 visible and infrared source images corresponding to the digital data are shown in Figures 1 and 2, respectively. For each of the SMS-1 data sets, digital samples of cloud data were extracted from raw digital VISSR image tapes prepared by NESS (National Environmental Satellite Service) for measuring low-level cloud motion vectors.

The VISSR image tapes for January 9, 1975 (at times 1600 z and 1630 z) consisted of 64x64 registered, paired arrays centered at fixed geographical locations (specified on the image tapes) ranging from 35°N to 35°S latitude and from 125°W to 25°W longitude (approximately 50° of longitude on each side of the sub-satellite point). The arrays are spaced at 5° intervals longitudinally and $2\frac{1}{2}$° latitudinally in an "offset" fashion over oceanic areas only. The resolution for the visible arrays is approximately 2x2 n.mi. and the resolution for the infrared arrays is approximately 2x4 n.mi. At the subsatellite point, the areal dimension of a 64x64 array of infrared data is approximately 104 n.mi. by 238 n.mi. and the areal dimension of a 64x64 array of visible data is approximately 104 n.mi. by 119 n.mi.

As a result of the differences in areal coverage, infrared and/or visible arrays had to be preprocessed in order to obtain both infrared and visible features for the same geographical sample area. Since visible data was not available for any region larger than 104 n.mi. by 119 n.mi. (at the sub-satellite point) around each fixed geographical location, only the central 64x32 pixels of the corresponding infrared array could be used. It seemed desirable to maintain the same scale (or resolution) for calculation of visible and infrared textural features and for output of visible and infrared sample data. This meant that visible arrays had to be averaged in the vertical direction (i.e., the elements in every two consecutive rows were averaged together) to form a corresponding 64x32 visible array with approximately 2x4 n.mi. resolution.

The conversion of the VISSR raw scanner signals into the raw VISSR digital data is described by Herkert et al. [2]. The visible channel sensors respond to energy in the 0.55 to 0.75 μm wavelength region which is converted into brightness values ranging from 0 (dark) to 63 (white). The infrared channel sensors pass scene radiation in the 10.5- to 12.6- μm wavelength region which is converted into calibrated counts ranging from 0 (dark) to 255 (white). Corresponding temperature values (degrees Kelvin) for infrared counts occurring in sample arrays are given in Table 1. Note from Table 1 that the temperature value decreases as infrared count increases.

The meteorological classification for the sample arrays in Data Sets II and III was constructed from a meteorological description of cloud types for the SMS-1 orbit of January 1, 1975, 1630 z. Two meteorologists, furnished with visible and infrared pictures of the satellite data for times 1630 z and 1600 z (shown in Figures 1-4), prepared a color-encoded cloud type description which is reproduced in Figure 5. Five cloud categories were distinguished:

1) low clouds
2) middle clouds
3) cirrus unmixed with other clouds
4) cirrus mixed with low and/or middle clouds
5) cumulonimbus and dense cirrus

Both cumulonimbus type clouds and the cirrus they produced were included in the last category. As the cirrus was carried away from its source and became thinner (revealing lower clouds), the classification was changed from category 5 to category 4. For the meteorological classification of sample data arrays in Tables 2 and 3, categories 1 and 2 (low and middle clouds, respectively) were combined into a "low" class. A sample data array was classified as "cirrus" only if the entire sample area fell within the outline of a category 3 (cirrus unmixed with other clouds) region. If any portion of a sample area overlapped a category 5 region, the sample was classified as "cumulonim-

bus". All other samples were classified as "mix".

The cloud-type classification and location of the sample arrays comprising the SMS-1 design set (Data Set II) are given in Table 2. The design samples were chosen to maximize the geographical coverage for samples within each cloud class while minimizing any uncertainty as to cloud-type classification due to manual misregistration of sample border and color-encoded category border. Using the geographic overlay of Figure 6 in conjunction with the meteorological color-encoded cloud-type description of Figure 5, an attempt was made to locate for each $2\frac{1}{2}°$ interval of latitude between 35°N and 35°S one sample of "low" cloud type, one sample of "mix" cloud type, one sample of "cirrus" cloud type, and one sample of "cumulonimbus" cloud type. "Cumulonimbus" samples and "cirrus" samples did not occur at every possible latitude within the given range. Only four samples of "cirrus" cloud could be found over oceanic regions between 35°N and 35°S latitude. In order to increase the number of cirrus samples within the design set, four "cirrus" data samples (Sample Numbers 78-81 in Table 2) were extracted from digital SMS-1 data for February 26, 1975, 2200 z, making a total of eight "cirrus" samples. The total number of design samples which were obtained by the above selection procedure was 81, distributed according to class as follows:

1) "low" class - 29 samples

2) "mix" class - 29 samples

3) "cirrus" class - 8 samples

4) "cumulonimbus" class - 15 samples

The samples in the test sets (Data Set III, large window size and small window size) consisted of all sample areas on the image tapes between the latitude limits of 12.5°N and 2.5°S. The location and classification for samples in the test sets is given in Table 3. For these samples, meteorological cloud-type classification was critically dependent on precise registration of sample boundaries with color-encoded cloud-type boundaries. The pictorial output of the original sample windows was also examined by a meteorologist to verify the cloud-type classifications for samples in Data Set III (large windows). When the window size changed from large to small, the cloud-type classification of 16 of the 107 test samples changed. The classification of the two "cirrus" samples in Data Set III (small window size) changed to "cumulonimbus" and "mix", respectively, for the large window size. The class frequencies for samples in Data Set III (small window size) were:

1) "low" class - 55 samples

2) "mix" class - 26 samples

3) "cirrus" class - 2 samples

4) "cumulonimbus" class - 24 samples

The class frequencies for samples in Data set III (large

window size) were:

1) "low" class - 44 samples

2) "mix" class - 30 samples

3) "cirrus" class - 0 samples

4) "cumulonimbus" class - 33 samples

3. <u>Analysis of Maximum Likelihood Classification of SMS-1 Data Sets</u>

A well-designed pattern recognition system should not be sensitive to minor variations in satellite sensor systems, satellite subpoint, or time of satellite orbit. The experiments in Table 4 were designed to determine the effect of the above factors on classification results. The pattern recognition systems which yielded the highest percentage of correctly classified NOAA-1 data samples described in [1] were designed and tested on SMS-1 Data Set II. Those experiments in Table 33 of [1] using maximum likelihood single-level classification with combinations of five features for which classification success was greater than 85% were repeated using SMS-1 Data Set II. All experiments in Table 35 of [1] using maximum likelihood single-level classification with combinations of seven features were repeated. In addition, the most successful experiment of Table 36 of [1] using maximum likelihood two-level classification for selected combinations of seven features (including quadrant features at the second stage to separate "low" and "mix" samples) was repeated for the SMS-1 data set. Several experiments for the three-class problem ("low", "cirrus", and "cumulonimbus") were also repeated.

There was no significant change in the classification results of Table 4 on SMS-1 data and the corresponding results on NOAA-1 data. The classification results for NOAA-1 maximum likelihood five-feature, single-level

classification in Table 33 of [1] corresponding to Experiments 1-5 of Table 4 ranged from 86.0% to 88.1%. The SMS-1 classification results for Experiments 1-5 (Table 4) ranged from 81.4% to 88.9%. For Table 35 of [1], NOAA-1 classification results ranged from 87.2% to 89.7% and corresponding SMS-1 classification results (Table 4) ranged from 85.2% to 88.9%. For Table 36 of [1], Experiment 1, NOAA-1 classification accuracy was 91.4% and the corresponding SMS-1 classification accuracy (Experiment 9, Table 4) was 85.2%. This indicated that, although classification accuracy may be improved when testing on a particular data set by increasing the design complexity of a pattern recognition system, the same improvement in classification accuracy may not be evidenced when the system is tested under a variety of conditions. Classification results for the three-class problem (separation of "low", "cirrus", and "cumulonimbus") in Experiments 10-16 of Table 4 ranged from 88.5% to 90.3% for single-feature combinations (Experiments 13 and 14), from 90.4% to 94.2% for two-feature combinations (Experiments 10, 11, and 15) and were 96.2% for the five-feature combinations (Experiments 12 and 16). Classification results for the NOAA-1 experiments corresponding to the SMS-1 Experiments 10-16 of Table 4 ranged from 98.1% to 98.7%. Confusion matrices for the experiments in Table 4 can be found in the Appendix to this report.

The optimistic bias of classification results obtained by designing and testing on the same data set was assessed by conducting a limited number of experiments using SMS-1 Data Set II as a design set and SMS-1 Data Set III (small window size) as a test set. The results of these experiments are presented in Table 5. The most successful experiments of Table 4 for the four-class problems (Experiments 3, 7, and 8) were repeated using SMS-1 Data Set III (small window size) as a test set. The classification results ranged from 77.6% to 81.3%, contrasted with classification results for the same experiments using the method of resubstitution (testing on the design set) of 86.4% to 89.7% for the NOAA-1 data set and 88.9% for SMS-1 Data Set II. This decrease of approximately 5 to 10% in classification accuracy did not occur for the well-defined three-class problem. In fact, classification results improved slightly from 96.2% (Experiment 16, Table 4) to 96.3% (Experiment 4, Table 5) when the test set was different from the design set. For the well-separated classes of the three-class problems, classification accuracy was not seriously affected by change in either design parameters of the pattern recognition system or factors such as change in testing procedure, satellite sensors, etc.

It can be seen from the confusion matrices presented in the Appendix that the major misclassification errors in Tables 4 and 5 resulted from "low", "cirrus",

or "cumulonimbus" samples falling into the "mix" class. The problem was particularly acute for "cumulonimbus" samples. When the window size was increased from 64x32 pixels (small window size) to 64x64 pixels (large window size), the problem of distinguishing a "cumulonimbus" sample with only a small portion of cumulonimbus-type cloud within the sample from a "mix" sample was magnified. Looking at Table 6 (Experiments 2 and 3 or Experiments 5 and 6), one can note the decrease in percentage of "cumulonimbus" samples correctly classified when the window size was increased (see also confusion matrices for Table 6 in the Appendix). As the window size was increased, the proportion of "cumulonimbus" samples in the test set was increased. The "a priori" probability of "cumulonimbus" samples for the design set was .19, and for the test set (large window size) .31.

Classification results for experiments in Table 6 can also be compared with the classification results of the cluster edge strength model described in another report [3]. Both the experiments in Table 6 and the cluster edge strength model use only infrared data. The most successful classification results of the experiments in Table 6 were 87.7% when testing on the design set and 77.6% when testing on SMS-1 Data Set III (small window size). In order to improve these classification results, image segmentation and scene analysis techniques (described

in [3]) were investigated. The four-class problem was reduced to the three-class problem of identifying "low" cloud segments, "cirrus" cloud segments, and "cumulonimbus" cloud segments. The final classification results of the cluster edge strength decision procedure (described in [3] on SMS-1 Data Set III (large window size) were 95.3% compared to results in the 70% and 80% range in Tables 4-6.

References

[1] J. A. Parikh, "Cloud pattern classification from visible and infrared data", Computer Science Center, Univ. of Maryland, College Park, Technical Report 442, February 1976. AD A033 037.

[2] J. Herkert. B. Remondi, B. Goddard, and W. Callicott, "An overview of the GOES data flow and processing facilities", U. S. Department of Commerce, Wash., DC, NOAA Technical Memorandum NESS 64, March 1975.

[3] J. A. Parikh and A. Rosenfeld, "Techniques for segmenting infrared cloud cover images", Computer Science Center, Univ. of Maryland, College Park, Technical Report 515, March 1977.

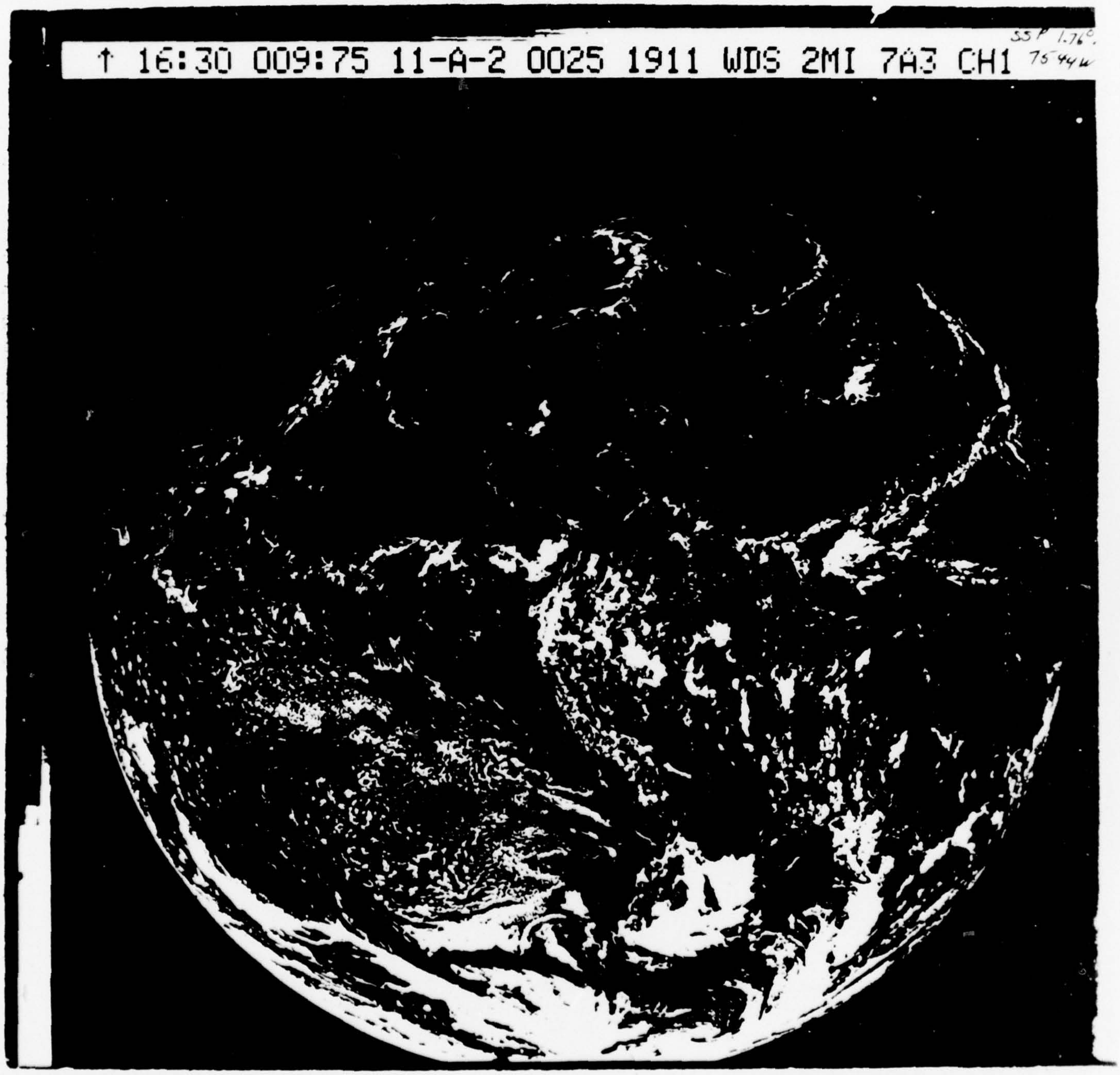

Figure 1. SMS-1 2x2-mile resolution visible picture, 1630 z, January 9, 1975.

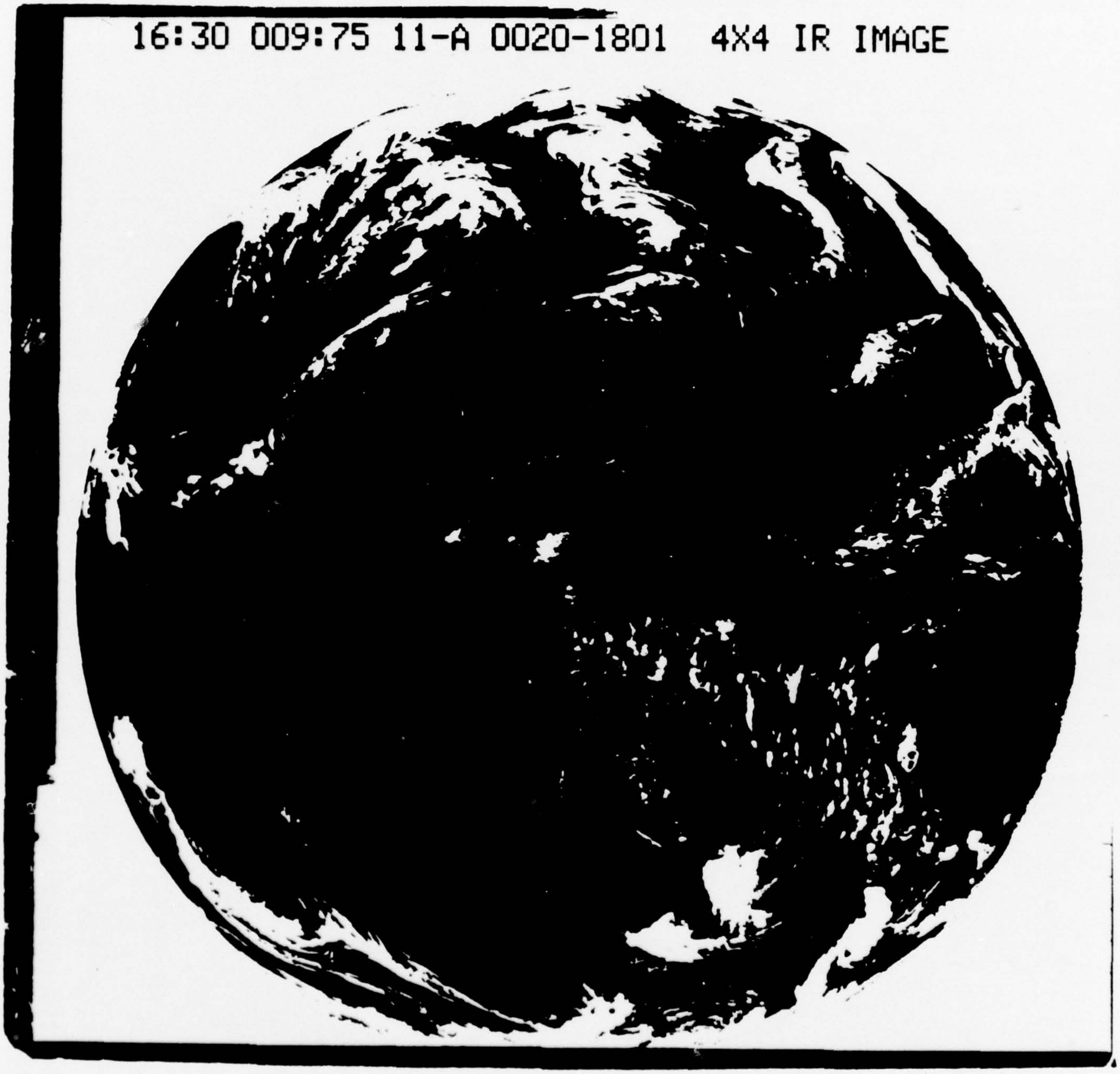

Figure 2. SMS-1 2x4-mile resolution infrared picture, 1630 z, January 9, 1975.

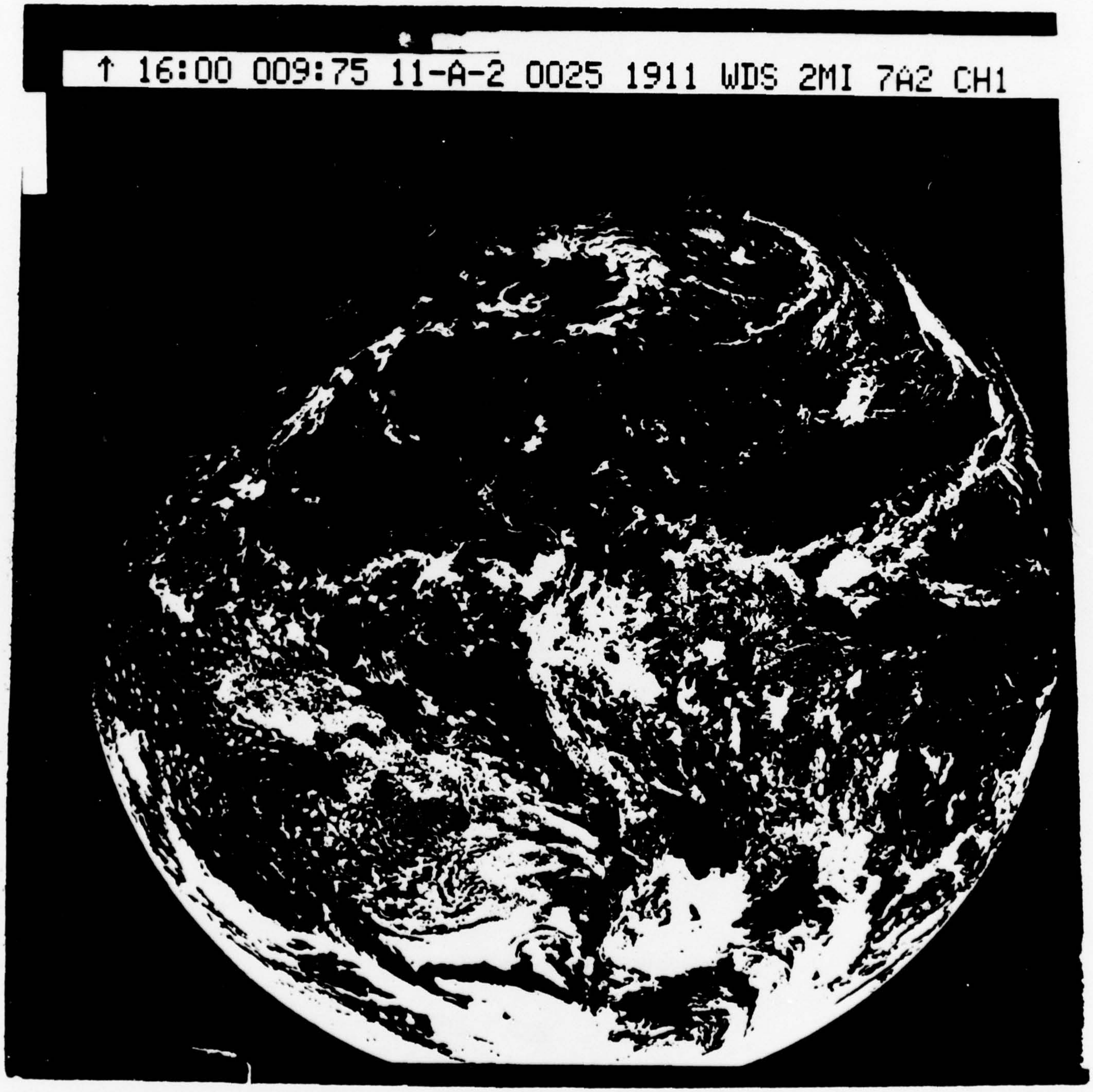

Figure 3. SMS-1 2x2-mile resolution visible picture, 1600 z, January 9, 1975.

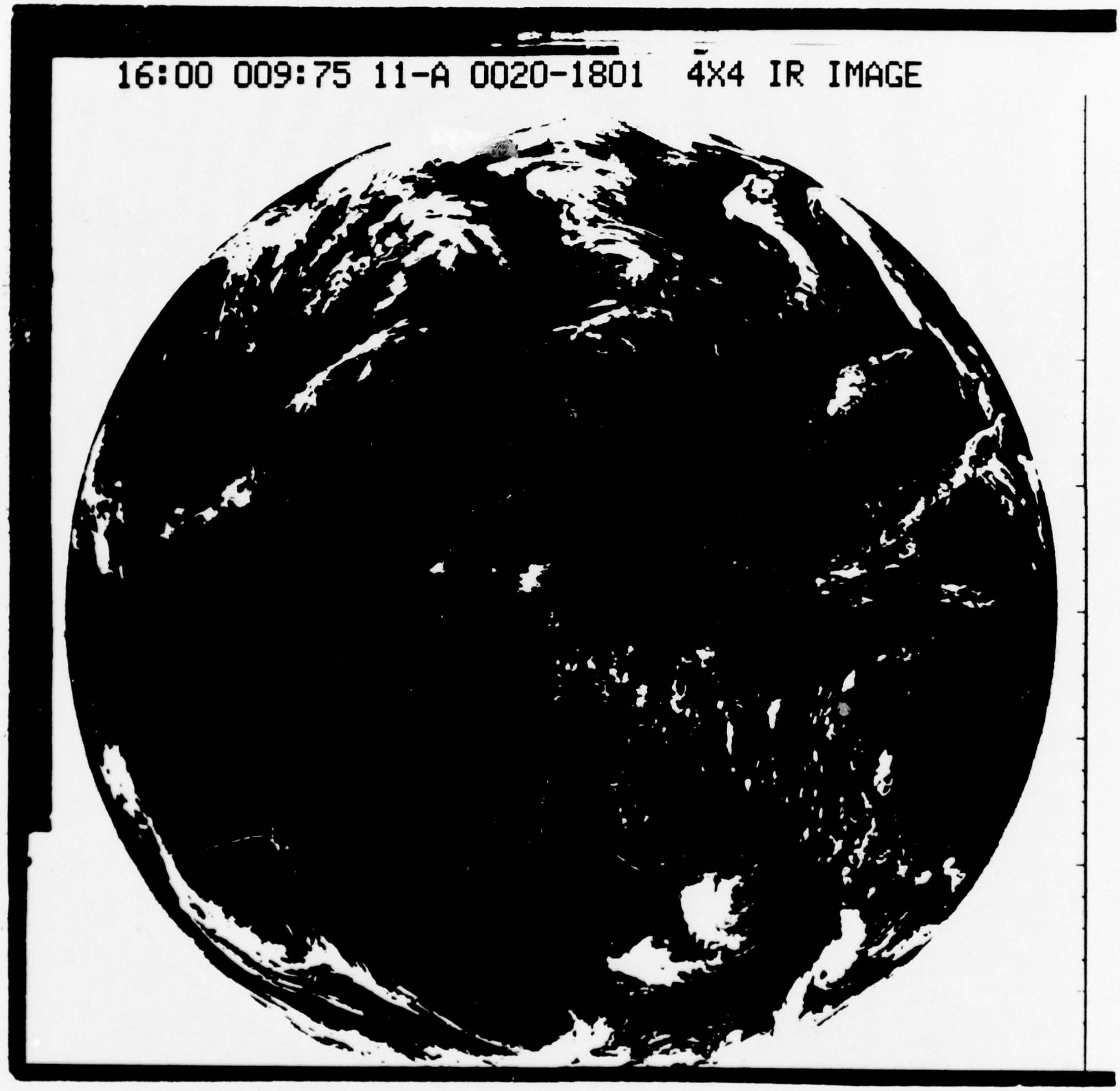

Figure 4. SMS-1 2x4-mile resolution infrared picture, 1600 z, January 9, 1975.

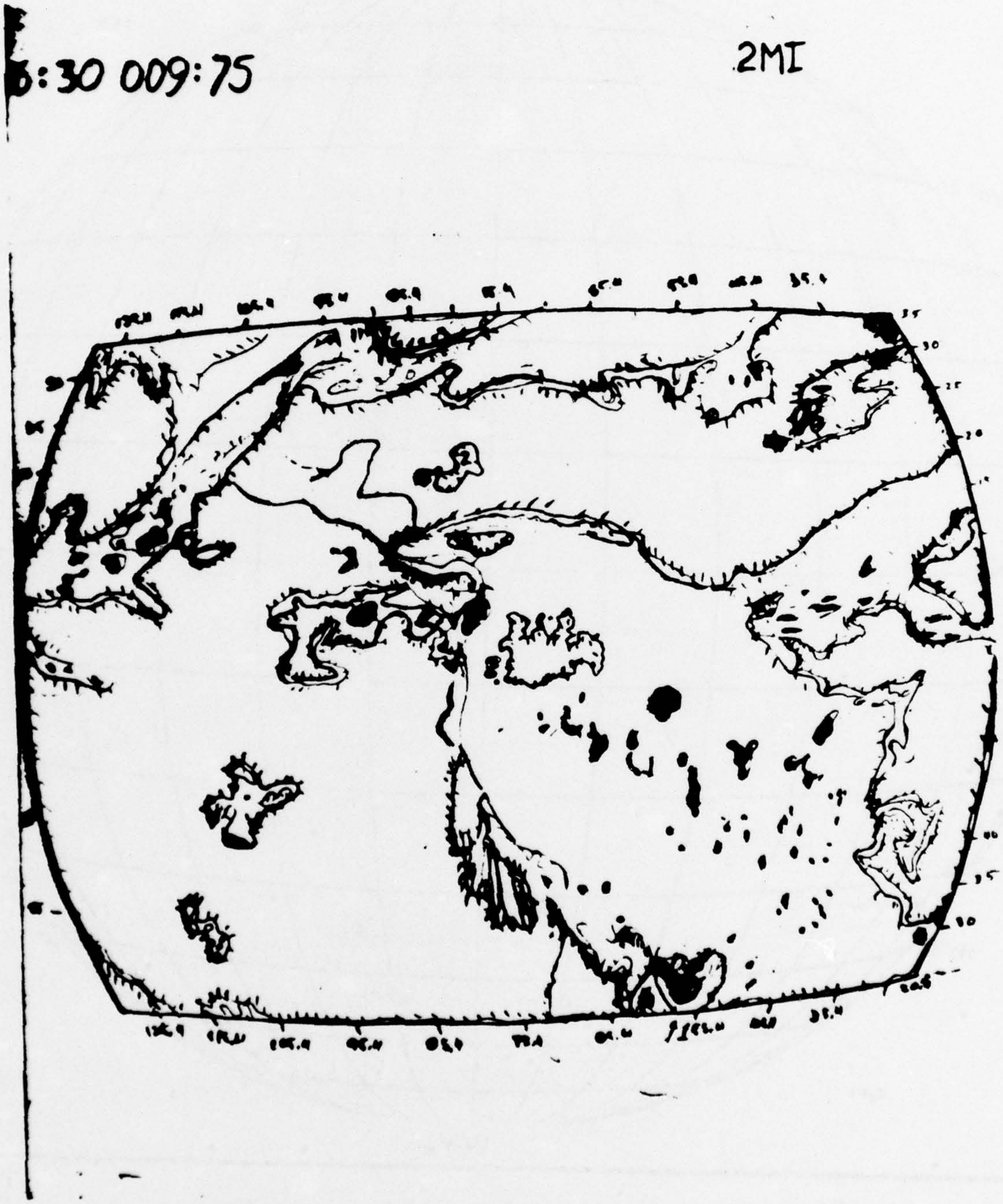

Figure 5. Color-encoded cloud type overlay for Figure 1.

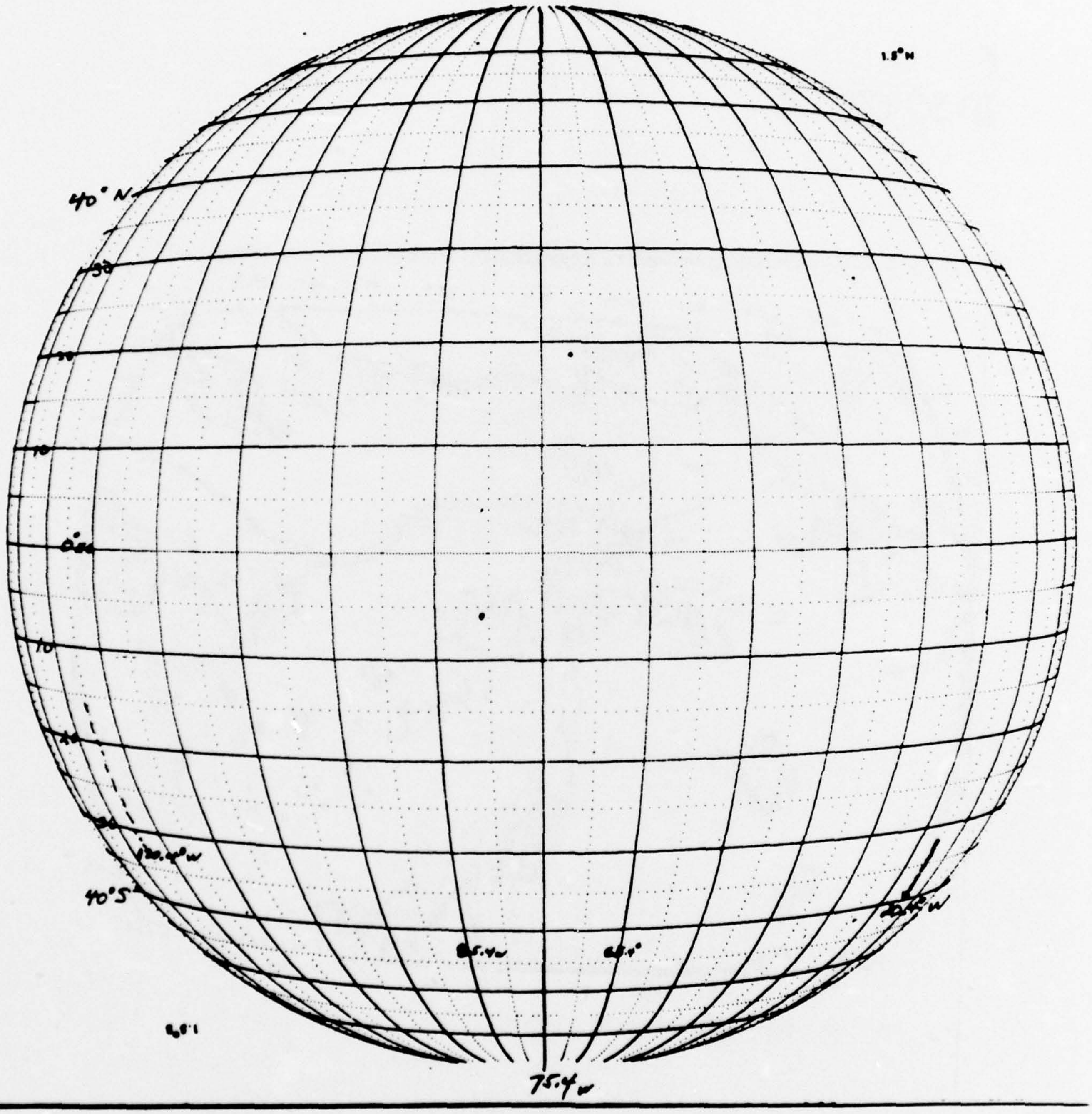

Figure 6. Latitude-longitude geodetic overlay for Figures 1-4.

Infrared Reading	Temperature (Degrees Kelvin)
50	304.99
51	304.58
52	303.77
53	303.36
54	302.94
55	302.53
56	302.12
57	301.70
57	301.28
58	301.87
59	301.45
60	300.02
61	299.68
62	299.18
62	298.75
63	298.32
64	297.89
65	297.46
66	297.03
67	296.60
68	296.16
69	295.73
69	295.29
70	294.85
71	294.41
72	293.97
73	293.52
74	293.07
75	292.63
76	292.18
77	291.72
77	291.27
78	290.82
79	290.36
80	289.91
81	289.44
82	288.98
83	288.51
84	288.15
85	287.58
86	287.11
87	286.63
88	286.16
89	285.68
90	285.20
91	284.72
92	284.24
92	283.76
93	283.27

Table 1. Calibration Table for SMS-1 Infrared Data.

Infrared Reading	Temperature (Degrees Kelvin)
94	282.78
95	282.29
96	281.79
97	281.30
98	280.80
99	280.30
100	279.79
101	279.29
102	278.78
103	278.27
104	277.75
106	277.24
107	276.72
108	276.20
109	275.67
110	275.15
111	274.62
112	274.08
113	273.55
114	273.01
115	272.47
116	271.92
117	271.38
118	270.82
119	270.27
121	269.71
122	269.15
123	268.59
124	268.12
125	267.45
126	266.87
127	266.30
129	265.71
131	264.54
132	263.95
133	263.35
135	262.75
136	262.14
137	261.53
138	260.92
139	260.30
141	259.68
142	259.05
143	258.42
144	257.78
146	257.14
147	256.49
148	255.84
150	255.18
151	254.12
152	253.85

Table 1 (cont'd)

Infrared Reading	Temperature (Degrees Kelvin)
154	253.18
155	252.50
156	251.81
158	251.12
159	251.42
161	249.72
162	249.01
163	248.29
165	247.57
166	246.84
168	246.10
169	245.35
171	244.61
172	243.85
174	243.08
175	242.30
176	241.52
177	240.72
178	239.92
179	239.11
180	238.29
181	237.45
181	236.61
182	236.76
183	234.90
184	234.02
185	233.14
186	232.24
187	231.32
188	230.40
189	229.46
189	228.51
190	227.54
191	226.56
192	225.56
193	224.54
194	223.51
196	222.46
197	221.38
198	220.29
199	219.18
200	218.04
201	216.88
202	215.64
204	214.48
205	213.24
206	211.97
207	210.67
209	209.33
210	207.96
211	206.54
213	205.88

Table 1 (cont'd)

Infrared Reading	Temperature (Degrees Kelvin)
214	203.68
216	202.03
218	200.42
219	198.76
221	197.02
223	195.22
225	193.33
227	191.36
229	189.28

Table 1 (cont'd)

Sample Number	Geographical Location Latitude, Longitude	Cloud Type Classification
1	35N, 55W	Mix
2	35N, 30W	Low
3	32.5N, 62.5W	Mix
4	32.5N, 32.5W	Low
5	30N, 70.0W	Mix
6	30N, 40.0W	Low
7	30N, 25W	Cb
8	27.5N, 122.5W	Low
9	27.5N, 67.5W	Mix
10	27.5N, 57.5W	Ci
11	27N, 47.5W	Cb
12	25N, 120.0W	Low
13	25N, 40W	Cb
14	25N, 35W	Mix
15	22.5N, 117.5W	Low
16	22.5N, 112.5W	Mix
17	22.5N, 42.5W	Cb
18	20N, 110W	Mix
19	20N, 95W	Low
20	20N, 45W	Cb
21	17.5N, 117.5W	Low
22	17.5N, 107.5W	Cb
23	17.5N, 27.5W	Mix
24	15N, 125W	Mix
25	15N, 110W	Cb
26	15N, 60W	Low
27	12.5N, 112.5W	Cb
28	12.5N, 92.5W	Low
29	12.5N, 67.5W	Mix
30	10N, 120W	Cb
31	10N, 95W	Low
32	10N, 45W	Mix
33	10N, 30W	Ci
34	7.5N, 97.5W	Low
35	7.5N, 57.5W	Mix
36	7.5N, 37.5W	Cb
37	5N, 100W	Low
38	5N, 45W	Cb
39	5N, 35W	Mix
40	2.5N, 102.5W	Low
41	2.5N, 42.5W	Mix
42	2.5N, 32.5W	Cb
43	0, 115W	Ci
44	0, 105W	Low
45	0, 45W	Mix
46	2.5S, 97.5W	Low
47	2.5S, 32.5W	Mix
48	5S, 10W	Low
49	5S, 35W	Mix

Table 2. Classification and Location of Data Samples for SMS-1 Design Set (Data Set II). Geographical location is specified for all samples extracted from SMS-1 digitized data for January 9, 1975, 1630 z.

Sample Number	Geographical Location Latitude, Longitude	Cloud Type Classification
50	7.5S, 112.5W	Low
51	7.5S, 102.5W	Mix
52	10S, 115W	Low
53	10S, 100W	Mix
54	12.5S, 102.5W	Mix
55	12.5S, 87.5W	Low
56	15S, 90W	Low
57	15S, 35W	Mix
58	17.5S, 92.5W	Low
59	17.5S, 32.5W	Mix
60	20S, 90W	Low
61	20S, 75W	Mix
62	22.5S, 87.5W	Low
63	22.5S, 77.5W	Mix
64	25S, 110W	Mix
65	25S, 100W	Low
66	25S, 45W	Cb
67	27.5S, 82.5W	Low
68	27.5S, 42.5W	Cb
69	27.5S, 37.5W	Mix
70	30S, 125W	Mix
71	30S, 90W	Low
72	30S, 25W	Cb
73	32.5S, 77.5W	Low
74	32.5S, 32.5W	Mix
75	35S, 110W	Mix
76	35S, 100W	Low
77	35S, 50W	Ci
78*		Ci
79*		Ci
80*		Ci
81*		Ci

*Data sample from SMS-1 digitized data for February 26, 1976, 2000 z.

Table 2. (cont'd)

Sample Number	Geographical Location Latitude, Longitude		Cloud Type Classification Large Windows	Small Windows
1	12.5N,	122.5W	Cb	Cb
2	12.5N,	117.5W	Cb	Cb
3	12.5N,	112.5W	Cb	Cb
4	12.5N,	107.5W	Mix	Mix
5	12.5N,	102.5W	Low	Low
6	12.5N,	97.5W	Low	Low
7	12.5N,	92.5W	Low	Low
8	12.5N,	82.5W	Mix	Mix
9	12.5N,	77.5W	Mix	Mix
10	12.5N,	67.5W	Mix	Mix
11	12.5N,	62.5W	Mix	Mix
12	12.5N,	57.5W	Low	Low
13	12.5N,	52.5W	Low	Low
14	12.5N,	47.5W	Low	Low
15	12.5N,	42.5W	Mix	Mix
16	12.5N,	37.5W	Cb	Cb
17	12.5N,	32.5W	Cb	Cb
18	12.5N,	27.5W	Cb	Cb
19	10N,	125W	Cb	Cb
20	10N,	120W	Cb	Cb
21	10N,	115W	Cb	Cb
22	10N,	110W	Cb	Low
23	10N,	105W	Low	Low
24	10N,	100W	Low	Low
25	10N,	95W	Low	Low
26	10N,	90W	Low	Low
27	10N,	80W	Mix	Mix
28	10N,	60W	Mix	Mix
29	10N,	55W	Mix	Low
30	10N,	50W	Mix	Mix
31	10N,	45W	Mix	Mix
32	10N,	40W	Cb	Cb
33	10N,	35W	Cb	Cb
34	10N,	30W	Cb	Ci
35	10N,	25W	Mix	Mix
36	7.5N,	122.5W	Cb	Cb
37	7.5N,	117.5W	Mix	Mix
38	7.5N,	112.5W	Mix	Mix
39	7.5N,	107.5W	Mix	Mix
40	7.5N,	102.5W	Low	Low
41	7.5N,	97.5W	Low	Low
42	7.5N,	92.5W	Low	Low
43	7.5N,	87.5W	Cb	Mix
44	7.5N,	82.5W	Cb	Low

Table 3. Classification and Location of Data Samples for SMS-1 Test Set (Data Set III Large Size and Small Size Windows). Geographical location is specified for samples from SMS-1 digitized data for January 9, 1975, 1630 z.

Sample Number	Geographical Location Latitude, Longitude		Cloud Type Classification Large Windows	Small Windows
45	7.5N,	57.5W	Mix	Mix
46	7.5N,	52.5W	Mix	Mix
47	7.5N,	47.5W	Mix	Mix
48	7.5N,	42.5W	Cb	Cb
49	7.5N,	37.5W	Cb	Cb
50	7.5N,	32.5W	Mix	Mix
51	7.5N,	27.5W	Low	Low
52	5N,	125W	Low	Low
53	5N,	120W	Low	Low
54	5N,	115W	Low	Low
55	5N,	110W	Low	Low
56	5N,	105W	Low	Low
57	5N,	100W	Low	Low
58	5N,	95W	Low	Low
59	5N,	90W	Cb	Cb
60	5N,	85W	Mix	Mix
61	5N,	80W	Cb	Cb
62	5N,	50W	Mix	Mix
63	5N,	45W	Cb	Cb
64	5N,	40W	Cb	Cb
65	5N,	35W	Mix	Mix
66	5N,	30W	Cb	Mix
67	5N,	25W	Cb	Low
68	2.5N,	122.5W	Mix	Low
69	2.5N,	117.5W	Mix	Low
70	2.5N,	112.5W	Low	Low
71	2.5N,	107.5W	Low	Low
72	2.5N,	102.5W	Low	Low
73	2.5N,	97.5W	Low	Low
74	2.5N,	92.5W	Low	Low
75	2.5N,	87.5W	Low	Low
76	2.5N,	82.5W	Low	Low
77	2.5N,	47.5W	Cb	Cb
78	2.5N,	42.5W	Cb	Cb
79	2.5N,	37.5W	Cb	Low
80	2.5N,	32.5W	Cb	Cb
81	2.5N,	27.5W	Cb	Cb
82	0,	125W	Mix	Low
83	0,	120W	Mix	Low
84	0,	115W	Mix	Ci
85	0,	110W	Low	Low
86	0,	105W	Low	Low
87	0,	100W	Low	Low
88	0,	95W	Low	Low
89	0,	90W	Low	Low
90	0,	85W	Low	Low
91	0,	45W	Cb	Cb
92	0,	40W	Mix	Low
93	0,	35W	Low	Low
94	0,	30W	Cb	Low
95	0,	25W	Cb	Mix
96	2.5S,	122.5W	Mix	Mix

Table 3 (cont'd)

Sample Number	Geographical Location Latitude, Longitude		Cloud Type Classification	
			Large Windows	Small Windows
97	2.5S,	117.5W	Low	Low
98	2.5S,	112.5W	Low	Low
99	2.5S,	107.5W	Low	Low
100	2.5S,	102.5W	Low	Low
101	2.5S,	97.5W	Low	Low
102	2.5S,	92.5W	Low	Low
103	2.5S,	87.5W	Low	Low
104	2.5S,	82.5W	Low	Low
105	2.5S,	37.5W	Cb	Cb
106	2.5S,	32.5W	Mix	Mix
107	2.5S,	27.5W	Low	Low

Table 3 (cont'd)

EXPERIMENT NUMBER	CORRESPONDING NOAA-1 EXPERIMENT	PERCENTAGE OF SAMPLES CORRECTLY CLASSIFIED				
		Low	Mix	Ci	Cb	Total
1	Table 33, Experiment No. 1	100.0	86.2	75.0	46.7	82.7
2	Table 33, Experiment No. 2	100.0	82.8	75.0	53.3	82.7
3	Table 33, Experiment No. 3	96.6	96.6	87.5	60.0	88.9
4	Table 33, Experiment No. 7	100.0	86.2	75.0	40.0	81.4
5	Table 33, Experiment No. 8	93.1	86.2	87.5	53.3	82.7
6	Table 35, Experiment No. 1	100.0	86.2	100.0	46.7	85.2
7	Table 35, Experiment No. 2	100.0	89.7	100.0	60.0	88.9
8	Table 35, Experiment No. 3	100.0	86.2	100.0	66.7	88.9
9	Table 36, Experiment No. 1	100.0	86.2	100.0	46.7	85.2
10	Table 41, Experiment No. 3	100.0	--	75.0	80.0	90.4
11	Table 41, Experiment No. 4	100.0	--	75.0	93.3	94.2
12	Table 41, Experiment No. 5	100.0	--	75.0	100.0	96.2
13	Table 42, Experiment No. 1	96.6	--	62.5	93.3	90.3
14	Table 42, Experiment No. 2	100.0	--	62.5	80.0	88.5
15	Table 42, Experiment No. 3	100.0	--	75.0	86.7	92.3
16	Table 42, Experiment No. 4	100.0	--	75.0	100.0	96.2

Table 4. Maximum Likelihood Classification of SMS-1 Design Samples (Data Set II) Using Both Visible and Infrared Features.

EXPERIMENT NUMBER	CORRESPONDING NOAA-1 EXPERIMENT	PERCENTAGE OF SAMPLES CORRECTLY CLASSIFIED				
		Low	Mix	Ci	Cb	Total
1	Table 33, Experiment No. 3	90.9	80.8	100.0	50.0	79.4
2	Table 35, Experiment No. 2	87.3	92.3	100.0	54.2	81.3
3	Table 35, Experiment No. 3	87.3	80.8	100.0	50.0	77.6
4	Table 41, Experiment No. 5	96.4	--	100.0	95.8	96.3

Table 5. Maximum Likelihood Classification of SMS-1 Test Samples (Data Set III, Small Windows) Using Both Visible and Infrared Features.

EXPERIMENT NUMBER	DATA SETS DESIGN	DATA SETS TEST	FEATURE SELECTION Features (Number, Name)	PERCENTAGE OF SAMPLES CORRECTLY CLASSIFIED Low	Mix	Ci	Cb	Total
1	Data Set II	Data Set II	(303,CF0),(314,R0-100),(315,R10-90),(350,Ent1D),(351,Ent2D)	96.6	89.7	50.0	40.0	79.0
2	Data Set II	Data Set III Small Windows	(303,CF0),(314,R0-100),(315,R10-90),(350,Ent1D),(351,Ent2D)	87.3	92.3	0.0	37.5	75.7
3	Data Set II	Data Set III Large Windows	(303,CF0),(314,R0-100),(315,R10-90),(350,Ent1D),(351,Ent2D)	84.1	93.3	---	15.2	65.4
4	Data Set II	Data Set II	(301,Mean),(302,StDev),(303,CF0),(314,R0-100),(315,R10-90),(350,Ent1D),(351,Ent2D)	100.0	89.7	100.0	53.3	87.7
5	Data Set II	Data Set III Small Windows	(301,Mean),(302,StDev),(303,CF0),(314,R0-100),(315,R10-90),(350,Ent1D),(351,Ent2D)	85.5	96.2	100.0	37.5	77.6
6	Data Set II	Data Set III Large Windows	(301,Mean),(302,StDev),(303,CF0),(314,R0-100),(315,R10-90),(350,Ent1D),(351,Ent2D)	75.0	100.0	---	21.2	65.4

Table 6. Maximum Likelihood Single-Level Classification of SMS-1 Samples Using Infrared Features Only.

APPENDIX

CONFUSION MATRICES

	Low	Mix	Ci	Cb
Low	29	0	0	0
Mix	0	25	1	3
Ci	0	1	6	1
Cb	0	8	0	7

Table 4. Experiment 1.

	Low	Mix	Ci	Cb
Low	29	0	0	0
Mix	0	24	2	3
Ci	0	1	6	1
Cb	0	6	1	8

Table 4. Experiment 2.

	Low	Mix	Ci	Cb
Low	28	1	0	0
Mix	0	28	0	1
Ci	0	0	7	1
Cb	0	6	0	9

Table 4. Experiment 3.

	Low	Mix	Ci	Cb
Low	29	0	0	0
Mix	0	25	2	2
Ci	0	2	0	6
Cb	0	9	0	6

Table 4. Experiment 4.

	Low	Mix	Ci	Cb
Low	27	2	0	0
Mix	2	25	1	1
Ci	0	0	7	1
Cb	0	7	0	8

Table 4. Experiment 5.

	Low	Mix	Ci	Cb
Low	29	0	0	0
Mix	0	25	1	3
Ci	0	0	8	0
Cb	0	8	0	7

Table 4. Experiment 6.

	Low	Mix	Ci	Cb
Low	29	0	0	0
Mix	0	26	1	2
Ci	0	0	8	0
Cb	0	6	0	9

Table 4. Experiment 7.

	Low	Mix	Ci	Cb
Low	29	0	0	0
Mix	0	25	1	3
Ci	0	0	8	0
Cb	0	5	0	10

Table 4. Experiment 8.

	Low	Mix	Ci	Cb
Low	29	0	0	0
Mix	0	25	1	3
Ci	0	0	8	0
Cb	0	8	0	7

Table 4. Experiment 9.

	Low	Ci	Cb
Low	29	0	0
Ci	0	6	2
Cb	0	3	12

Table 4. Experiment 10.

	Low	Ci	Cb
Low	29	0	0
Ci	0	6	2
Cb	0	1	14

Table 4. Experiment 11.

	Low	Ci	Cb
Low	29	0	0
Ci	0	6	2
Cb	0	0	15

Table 4. Experiment 12.

	Low	Ci	Cb
Low	28	1	0
Ci	1	5	2
Cb	0	1	14

Table 4. Experiment 13.

	Low	Ci	Cb
Low	29	0	0
Ci	1	5	2
Cb	0	3	12

Table 4. Experiment 14.

	Low	Ci	Cb
Low	29	0	0
Ci	0	6	2
Cb	0	2	13

Table 4. Experiment 15.

	Low	Ci	Cb
Low	29	0	0
Ci	0	6	2
Cb	0	0	15

Table 4. Experiment 16.

	Low	Mix	Ci	Cb
Low	50	5	0	0
Mix	2	21	3	0
Ci	0	0	2	0
Cb	0	12	0	12

Table 5. Experiment 1.

	Low	Mix	Ci	Cb
Low	48	7	0	0
Mix	1	24	0	1
Ci	0	0	2	0
Cb	0	11	0	13

Table 5. Experiment 2.

	Low	Mix	Ci	Cb
Low	48	7	0	0
Mix	0	21	2	3
Ci	0	0	2	0
Cb	0	12	0	12

Table 5. Experiment 3.

	Low	Ci	Cb
Low	53	0	2
Ci	0	2	0
Cb	0	1	23

Table 5. Experiment 4.

	Low	Mix	Ci	Cb
Low	28	1	0	0
Mix	0	26	1	2
Ci	0	4	4	0
Cb	0	8	1	6

Table 6. Experiment 1.

	Low	Mix	Ci	Cb
Low	48	7	0	0
Mix	1	24	0	1
Ci	0	2	0	0
Cb	0	15	0	9

Table 6. Experiment 2.

	Low	Mix	Ci	Cb
Low	37	7	0	0
Mix	0	28	0	2
Ci	0	0	0	0
Cb	0	28	0	5

Table 6. Experiment 3.

	Low	Mix	Ci	Cb
Low	29	0	0	0
Mix	0	26	0	3
Ci	0	0	8	0
Cb	0	7	0	8

Table 6. Experiment 4.

	Low	Mix	Ci	Cb
Low	47	8	0	0
Mix	0	25	0	1
Ci	0	0	2	0
Cb	0	15	0	9

Table 6. Experiment 5.

	Low	Mix	Ci	Cb
Low	33	11	0	0
Mix	0	30	0	0
Ci	0	0	0	0
Cb	0	26	0	7

Table 6. Experiment 6.

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